Ocean Optical Modeling: The Complex Optical Field Structure and Dynamics of Coastal Case 2 Waters

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LONG-TERM GOALS

Mechanistically-based models and algorithms for ocean optical phenomena are the basis of this project. Models derived from these considerations are robust, reliable, and most importantly -- transportable. Thus a standard optical model for the oceans is in development. The requirement for constructing a standard model is a simple and reliable parameterization. The parameterizaition here is based on chlorophyll and suspended minerogenic matter.

OBJECTIVES

My efforts are directed toward a coastal ocean, Type 2 water, optical model. The major efforts are to account for the effects of suspended and resuspended particulate minerogenic matter.

APPROACH

A reasonable start for modeling complex coastal ocean systems is the relationships determined for open ocean paradigms. The Open Ocean Optical Model (Weidemann, et al, 1995) provides this with a standardized suite of known inherent optical properties for the deep ocean. I use a chlorophyll based parametrization of this suite of inherent optical properties. This model is the basis for modeling the total scattering coefficient of the suspended organic matter. Stramski and Mobley (1997) propose volume scattering functions for various cell types that may be very useful for extending the organic scattering model. However, the critical information is the mass concentration and size distribution of minerogenic particulates. Such data are not routinely collected and thus we turn to a hydrodynamic modeling approach. The hydrodynamic model we use is Dr. Timothy Keen's sub-regional very high resolution model, Trans98, that he has applied to the Oceanside, California, October 1995, field site of the Littoral Optical Environment (LOE) initiative of the Naval Research Laboratory (NRL). Specifically, Trans98 utilizes the wave-current interaction bottom boundary layer model (BBLM) described by Keen and Glenn (1998) and Glenn and Grant (1987) to calculate suspended sediment profiles. The bottom currents to drive the model came from Acoustic Doppler Current Profiler surveys or 2D fields derived from the Princeton Ocean Model (Oey and Chen, 1992). Local data collected on tides, wind stress, and wave heights coupled with the excellent characterization of the bottom sediments by Inman (1953) allowed the determination of the vertical profile of resuspended sediments. One of premier featues of the Trans98 model is the characterization of sediment profiles on a very fine

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grid, 900 m in the x-direction (60 grid points) and 600 m in the y-direction (113 grid points). Thus individual oceanographic moorings in the Oceanside, 1995, exercise were modeled and characterized.

The Inman (1953) report indicates that the sediments in this area are quartz sand and silt and the individual particles are thus approximately spherical. Polydisperse Mie calculations give a volume scattering function and total scattering coefficient for the resuspended sediments. A regression (Haltrin et al. 1999) derived from the polydisperse Mie calculations is coupled with the Trans98 model for calculating the total scattering coefficient of the resuspended sediments. We have described this modeling approach for the optical environment of the near shore region as the bottom up approach. This is in contrast to the top down approach which accounts for the optical effects of living cells intercepting the solar flux near the surface layers -- typical of open ocean models and algorithms. The bottom up approach, accounting for resuspension from the bottom, is of course complementary with the top down approach and both are needed for modeling the optics of the coastal region. The Trans98 model supplies the information on scattering by the resuspended sediments and the Open Ocean model of the NRL supplies information on scattering by organic suspended matter. The open Ocean Model easily estimates the absorption coefficient of the coastal ocean (Stavn et al. 1998). With this total suite of information on coastal inherent optical properties, I simulate the solution of the radiative transfer equation by Monte Carlo methods on the Cray T3E and more recently on the Origin2000 at the North Carolina Supercomputing Center. Parallelization of the Monte Carlo simulations has increased their efficiency by orders of magnitude. This method easily accounts for the complicated non-linearities introduced by multiple scattering, internal radiant emission, and internal apparent radiance sources, i.e. reflective bottoms and wave-disturbed water/air interfaces. Combining this information with the ease of determining the absorption coefficient remotely allows the partitioning of the total scattering coefficient into minerogenic and organic components. The combination of remotely sensed data with bottom up simulations is being actively developed right now to provide much greater accuracy for remote sensing algorithms of the coastal ocean. The rationale for these efforts is the difference in the nature of the total scattering coefficient for minerogenic matter compared with organic matter -- which may account for the present difficulties in the remote sensing of the coastal ocean. The methods worked out at Oceanside, CA are presently being tested for relocatablility on the LOE field investigation at Hamlet's Cove, Eglund Air Force Base, Florida.

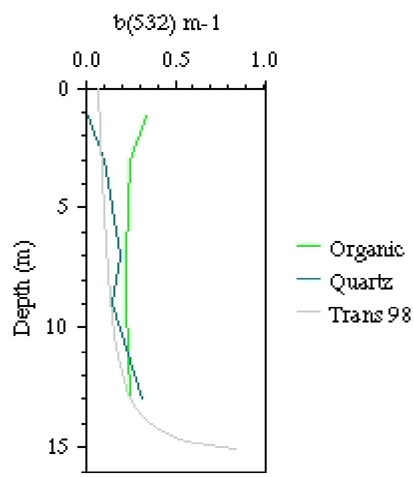
WORK COMPLETED

Fundamental verification of the chlorophyll-sediment bio-geooptical coastal model has been completed. The stations with complete data on optical properties from AC-9 measurements, chlorophyll and dissolved-suspended organic matter concentration, and winds, wave heights, and bottom currents provided the verification. Comparisons of the predictions of the minerogenic scattering component from the Trans98 model and the NRL Open Ocean Model have been completed. The predictions from the entirely different approaches were confirmed, for the stations exhibiting complete field data, to a level of accuracy rarely approached before. The fine resolution of data on chlorophyll and suspended-dissolved organic matter allowed an expansion and extension of the Open Ocean Model predictive capabilities (Keen and Stavn, 1999).

RESULTS

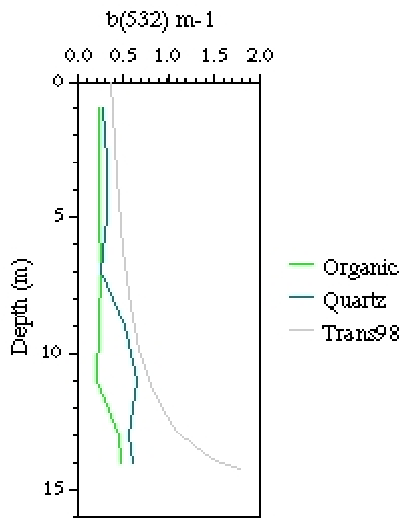
Increased refinements of the Trans98 model allowed extension of the predictions of the near-shore resuspension of minerogenic matter, even with rather mild meterological and external forcing conditions (wave heights less than 1 m) as reported in Keen and Stavn (1999). The stations chosen for verification were called the "optical line," a transect that extended perpendicularly from shore, from about 33.233 lat. x -117.417 long. To about 33 m depth. Optical variations between and within the field stations were accounted for by the Trans98 model (Figs. 1 and 2, Keen and Stavn, 1999). The correlation of the sediment resuspension activity with significant wave height was confirmed in the report of the optical activity at Oceanside, CA being correlated with this wave height activity (Johnson et al. 1999). Sediment resuspension activity at Oceanside, CA was routinely reported for the stations from 7 to 18 m depth. Some activity was indicated for stations at 25 m depth while a few days out of the approximately 10 day period of the exercise exhibited sediment resuspension at the 30 meter stations. The total scattering activity of the deepest station, OS3, on one date utilized for verification, 24. Oct 1995 UT, was accounted for by the chlorophyll portion of the bio-geooptical model. On the first verification date, 21 October 1995, the scattering coefficient at 532 nm due to suspended algae and organic detritus was calculated from the Open Ocean model and then the quartz scattering coefficient was determined by subtracting the organic scattering coefficient from the total scattering coefficient recorded from the AC-9 meter at that station. The quartz scattering agreed quite well with the Trans98 minerogenic scattering coefficient (Fig. 1).

1. Station OM1 21 October 1995 UT.



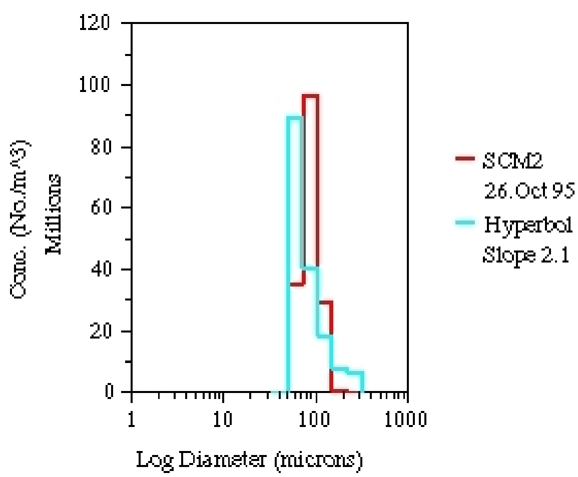
The AC-9 reading for Station OM1 on 24 October 1995, the other verification date, was not as reliable and required reconstructing the probable curve from an adjacent station and from the AC-9 reading at 1.6 m off the bottom from an instrument attached directly to the mooring. This curve also shows good agreement between the determinations from the Open Ocean model and AC-9 profile and the predictions from the Trans98 model (Fig. 2).

2. Station OM1, 24. October 1995 UT



One result of a realistic simulation, physically based, of sediment resuspension in the coastal region is a realistic particle size-distribution for the resuspended sediment. An assumption often made in attempts to model the optical effects of various particle size ditributions in the ocean is an exponential distribution of the concentrations of particles in the various size classes. One modeling of the optical

3. Station SCM2, 26. October 1995 UT.



effects at the Oceanside, CA site had the assumption that the particle size classes followed an exponential, or hyperbolic, slope of 2.1 (Schoonmaker et al. 1994). I compare here the particle size distribution from the Trans98 model with the same total particle concentration for which a size distribution with slope 2.1 has been calculated (Fig. 3). The data of Fig. 3 are the size distribution for Station SCM2 quartz-like particles at 0.13 meters off the bottom. There were extensive data on total particle concentration and chlorophyll for 26 October 1995 (Roesler, 1995) and these provided the data needed for comparisons with our model predictions. The particle distribution for the Trans98, physically based realistic simulation of sediment resuspension, exhibits a modal size class 73 µm while the exponential (hyperbolic) distribution of slope 2.1 exhibits a modal size class of 50 µm. The total scattering coefficient for the suspended minerogenics on the exponential assumption was about 40% higher than the scattering coefficient calculated from the Trans98 sediment suspension. Such a result is consistent with an overestimate of the scattering coefficient reported in the study assuming an exponential size distribution of the suspended sediment at Oceanside, CA for an earlier date (Schoonmaker et al. 1994). A further verification of the predictions of the total particle concentration from the Trans98 model comes from comparing the total particle concentration for Station SCM2 at 26. October 1995 UT measured with the Galai CIS 100 meter (Roesler, 1995). The predicted concentration of resuspended sediment for Station SCM2 in the surface layer on 26. October 1995 was on the order of 10 million particles per m^3. The measured concentration of particles in the surface layer was on the order of hundreds of millions of particles per m^3. This indicates that the predicted minerogenic particle concentration is consistent with direct measurements of particles, the difference in numbers near the surface due no doubt to the concentration of algal particles and organic detritus in this layer.

We have verified the use of the chlorophyll-sediment model to predict the optical properties (absorption and scattering coefficients) for the coastal region. The discrepancy between the scattering coefficient calculated by the Open Water model and the scattering coefficient measured by the AC-9 meter has been shown to be due to suspended minerogenic matter in the coastal ocean. We have demonstrated that the size distribution of the minerogenic particulates does not follow the over-simplified hyperbolic size distribution, which can introduce serious errors in the calculation of the scattering coefficient.

IMPACT/APPLICATIONS

These simulations of minerogenic matter coupled with accurate estimates measurements of chlorophyll and suspended organic matter have verified a predictive near shore optical model. The assessment of the mass concentration and size distribution of minerogenic matter near the surface will have strong implications for remote sensing of the coastal ocean. This model will improve both passive and active (expected return from a laser probe) remote sensing efforts as the nature of the backscattering coefficients will be better known. Underwater visibility studies will be improved from determinations of multiple scattering and multiple internal reflections from knowledge of the optical consequenses of mass concentration and size distribution of minerogenic particles.

TRANSITIONS

The knowledge gained from our Type 2 water studies of suspended minerogenic and organic matter concerning effects on the backscattering coefficient are being utilized by Frank Hoge, NASA - Wallops Island, VA, for active remote sensing work in coastal regions. Sonia Gallegos and Rick Gould of the Remote Sensing Branch, NRL-Stennis are interested in applying these results to remote-sensing algorithms for the Yellow Sea and high minerogenic coastal remote sensing algorithms. The Louisiana Universities Marine Consortium (LUMCON) has expressed interest in these results for studies of the coastal system at Terrebonne Bay, Louisiana and the Mississippi River Plume in the Gulf of Mexico.

Dr. Gregg Booth, Earth System Science Office, NASA, SSC, MS is wanting some of these results in the remote assessment of suspended minerogenic matter in the Gulf of Mexico.

RELATED PROJECTS

Herewith I list the projects being pursued concurrently with the Littoral Optical Environment initiative of the Naval Research Laboratory and the Office of Naval Research.

1 - Timothy R. Keen, Ocean Dynamics and Prediction Branch (Code 7322), Naval Research Laboratory, Stennis Space Center, MS is working closely with me to provide very high resolution results for a given latitude and longitude for mass, size distribution, and type of resuspended minerogenic material from the Trans98 model. This is being done through the Very High Resolution 4-D Coastal Ocean Currents Program element 62435N of ONR. We are presently working up the LOE results from Hamlet's Cove, Florida. Next is a study of the Chesapeake Bay.

2 - John Kindle, Coupled Dynamic Processes Section (Code 7331), Ocean Sciences Branch (Code 7330), Naval Research Laboratory, Stennis Space Center, MS has been interested in the optimal wavebands to utilize in a surface layer model of hydrodynamically forced primary productivity in the Arabian Sea. We have been discussing ways of incorporating minerogenic results into some of his group's modeling efforts.

3 - Vladimir I. Haltrin, Coupled Dynamic Processes Section (Code 7331), Ocean Sciences Branch (Code 7330), Naval Research Laboratory, Stennis Space Center, MS has been working with me on optimized codes for Mie Scattering calculations and on scattering properties of small clay particulates. We are currently considering Mie type codes for volume scattering functions of non-spherical particles.

4 - Dariusz Stramski, Marine Physical Laboratory, Scripps Institution of Oceanography, UCSD, La Jolla, CA has a database of optical properties of living and organic suspended particles (Stramski and Mobley, 1997). We will be using this database in various radiative transfer simulations. The more interesting results will be jointly published.

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PUBLICATION

Keen, T. R. and R. H. Stavn, 1999: Developing a capability to forecast coastal ocean optics: minerogenic scattering, in *International Conference on Estuarine and Coastal Modeling 6, Proceedings, eds*. M. Spaulding and A. Blumberg, New Orleans, LA, Nov. 3-5 (submitted).